

Original article

Distinction between fill channels and abrasion furrows on ammonoid internal moulds

Distinction entre canaux de remplissage et sillons d'abrasion dans les moules internes d'ammonoïdes

Distinción entre canales de relleno y surcos de abrasión en los moldes internos de ammonites

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Abstract

Ammonoid sedimentary internal moulds can display grooves on the external or ventral region that have been formed by diverse taphonomic processes. In particular, draft-filling spiral channels and abrasion annular furrows are taphonomic structures useful as palaeoenvironmental indicators of turbulent waters and conditions of low rate of sedimentation, although they can show some common morphological properties that may lead to erroneous identifications. However, the morphological features, formation processes and palaeogeographic conditions in which the structures of these two types have been developed are very different. In consequence, it is important to keep in mind the distinctive characters of these taphonomic structures before using their occurrence in the palaeoenvironmental or palaeogeographic interpretations.

Résumé

Les moules internes formés par remplissage sédimentaire des coquilles d'ammonoïdes peuvent présenter des canaux et des sillons dans la région externe ou ventrale, qui ont été générés par divers processus taphonomiques. En particulier, les canaux spiraux de remplissage sédimentaire et les sillons annulaires d'abrasion sont des structures taphonomiques utiles comme indicateurs paléoenvironnementaux de régimes turbulents et de conditions de baisse de taux de sédimentation, bien qu'ils puissent présenter quelques propriétés morphologiques communes pouvant conduire à des identifications erronées. Néanmoins, tant les traits morphologiques que les processus de formation et les conditions paléogéographiques dans lesquelles se sont développées les structures de ces deux types sont très différentes. En conséquence, il est important de prendre en considération les caractères distinctifs de ces structures taphonomiques avant d'utiliser leur présence dans les interprétations paléoenvironnementales ou paléogéographiques.

Resumen

Los moldes internos de ammonites formados por relleno sedimentario de las conchas pueden presentar surcos y canales en la región externa o ventral que han sido generados por distintos procesos tafonómicos. En particular, los canales espirales de relleno sedimentario y los surcos anulares de abrasión son estructuras tafonómicas útiles como indicadores paleoambientales de regímenes turbulentos y condiciones de baja tasa de sedimentación, aunque pueden presentar algunas propiedades morfológicas comunes que pueden llevar a identificaciones erróneas. Sin embargo, tanto los rasgos morfológicos, como los procesos de formación y las condiciones paleogeográficas en las que se han desarrollado las estructuras de

estos dos tipos, son muy diferentes. En consecuencia, es importante tener en cuenta los caracteres distintivos de estas estructuras tafonómicas antes de utilizar su presencia en las interpretaciones paleoambientales o paleogeográficas.

Keywords: Ammonoidea; Jurassic; Taphonomy; Fossilization; Sedimentary palaeoenvironments; Palaeogeographic analysis

Mots clés : Ammonoidea ; Jurassique ; Taphonomie ; Fossilisation ; Paléoenvironnements sédimentaires ; Analyse paléogéographique

Palabras clave: Ammonoidea; Jurásico; Tafonomía; Fossilización; Paleoambientes sedimentarios; Análisis paleogeográfico

1. Introduction

Fill channels and abrasion furrows occur on ammonoid internal moulds of complete shells as well as of incomplete phragmocones, and they show a number of properties in common. The features of some fill channels developed on the external region of ammonoid sedimentary internal moulds have been investigated by Seilacher (1968, 1971, 1973); Mundlos (1970); Düringer (1982); Hagdorn and Mundlos (1983) and Fernández-López (1997a). Similarly, the characteristics of some abrasion furrows have been studied by Fernández-López (1985, 1995) and Fernández-López and Meléndez (1994, 1995).

The purpose of this paper is to provide diverse criteria for a correct distinction between draft-filling spiral channels and abrasion annular furrows, taking into account their relevance for palaeoenvironmental and palaeogeographic interpretations of fossiliferous deposits in Mesozoic carbonate epicontinental platforms.

2. Fill channels

According to data from the fossil record, soft parts, periostraca and siphuncular tubes of ammonoids showed increasing values of durability during biodegradation-decay processes (Seilacher et al., 1976, 1985; Hagdorn and Mundlos, 1983; Maeda and Seilacher, 1996; Fernández-López, 1997a, 1999, 2000a, 2000b). All these organic components of ammonoid remains could be biodegraded and destroyed in well-oxygenated marine waters, before the burial of the shells. In contrast, ammonoid shells maintaining soft parts in the body chamber and periostraca during early diagenesis should be more common in poorly oxygenated environments, associated with more protected, restricted or deeper environmental conditions, as well as in environments of high rate of sedimentation and high rate of sediment accumulation.

Empty chambers of ammonoid shells could be filled with sedimentary particles before and after the burial. As a general rule, the sedimentary infill was introduced in the chambers by draft currents produced by outside turbulence (cf. Seilacher, 1963, 1966, 1971, 1973; Schindewolf, 1967; Mundlos, 1970; Seilacher et al., 1976; Düringer, 1982; Hagdorn and Mundlos, 1983; Maeda and Seilacher, 1996; Fernández-López, 1997a, 2000b). The generation of draft hydraulic currents inside the shells would require that the chambers were communicated with the exterior by some orifice and the existence of a turbulent regime in the proximity of the shell. According to Bernoulli's principle, if the outside turbulence could act on the orifice, a

vacuum able to suck water with sedimentary particles in suspension into the shell could be produced in the phragmocone chambers. The stronger the turbulence, the greater the suction, and so the sedimentary particles would be transported farther up the phragmocone. On the contrary, unbroken chambers keeping the siphuncular tubes or soft-parts still articulated would in turn continue being empty of sedimentary fill.

However, the sediment transported by draft currents towards the interior of the shell chambers is a load deposit, carrying particles in suspension; therefore, other extrinsic factors such as the size of the available sedimentary particles, the rate of sedimentation (calculated by dividing the thickness of sediment by the total time interval including the gaps) and the rate of sediment accumulation (estimated by dividing the thickness of sediment by the time interval of positive net sedimentation) may also affect these filling processes of shells. In particular, the probability of shells to be filled with sediment will be inversely proportional to the rate of sedimentation and to the rate of sediment accumulation. Hollow ammonites (i.e., shells showing no sedimentary infill in the phragmocone) are dominant in expanded sections, formed in conditions of high rate of sedimentation and high rate of sediment accumulation, although they are usually compressed by gravitational diagenetic compaction (Fernández-López, 1997a, 1997b, 2000a, 2000b; Reboulet et al., 2003). Expanded deposits formed by turbulence events under conditions of high rate of sediment accumulation, such as tempestites or turbidites, even in environments of low rate of sedimentation and associated with condensed sections, often contain hollow ammonites too. In contrast, ammonoids displaying phragmocones with complete and homogeneous sedimentary infill are common in condensed sections formed by condensed deposits, resulting from low values of both rate of sedimentation and low rate of sediment accumulation, in distal and deep marine environments (Fernández-López, 1997a, 1997b; Fernández-López et al., 1999, 2000, 2002; Fernández-López and Meléndez, 2004a, 2004b). Conversely, empty phragmocones showing no sedimentary infill (i.e., hollow ammonites) or phragmocones with heterogeneous sedimentary infill are common in condensed sections, of low rate of sedimentation, formed by expanded deposits of high rate of sediment accumulation in proximal and shallow marine environments (Fernández-López and Gómez, 1990; Gómez and Fernández-López, 1994; Fernández-López, 1997a, 1997b, 2000a, 2000b).

One of the clearest indications of the performance of intracameral draft streams on ammonoid shells, from the body chamber towards the apical chambers and through the septal foramina, is the occurrence of a sinuous-shaped groove in, or a

subcylindrical hollow conduct near of, the outer surface of some sedimentary internal moulds. These superficial grooves and subsurface conducts pass through the septal necks along the mid-line of the ventral region on the phragmocone or connect the last septal foramen with the opening of the body chamber (Figs. 1–3). The existence of a sinuous groove on the outer surface of some internal moulds, which can describe a regular sinusoidal or crenulated pattern between any two consecutive septa, provides a positive indication of the filling process of the camerae based on the principle of the through draft and the nature of the sedimentary filling mechanism in the ammonoid shells (Lehmann, 1976).

The mechanical stability of taphonomic elements, their azimuthal orientation and inclination, as well as the position and size of the orifices of the internal cavities are other intrinsic factors influencing the processes of sedimentary infilling of shells. Specimens bearing such fill channels are most commonly discoidal and planispiral moulds, platycones or cadycones, more rarely oxycones and never globular sphaerocones. These fill structures have been observed on internal

moulds ranging from 15 to 250 mm diameter, and showing values of whorl thickness to diameter ratio between 0.15 and 0.60.

Furthermore, preservation of the produced fill channels requires early mineralization of the ammonoid internal moulds or of their sedimentary matrix, before compression by gravitational diagenetic compaction, in order to avoid diagenetic distortions. The proportion of clay must have influenced the maximum degree of consolidation attained by carbonate concretionary internal moulds of ammonoids or their sedimentary matrix. In particular, if clay exceeds 2% in calcilutites, early cementation is inhibited and compaction will occur on subsequent loading (Goldring and Kazmierczak, 1974). Consequently, complete or partial, concretionary internal moulds of ammonoids showing carbonate sedimentary infill and draft-filling spiral channel are indicative of subtidal environments, with turbulent regime and low rate of sedimentation conditions (due to winnowing action on the seafloor, sediment bypass or sediment starving). Distal and deep palaeoenvironments, in condensed deposits of low rate of

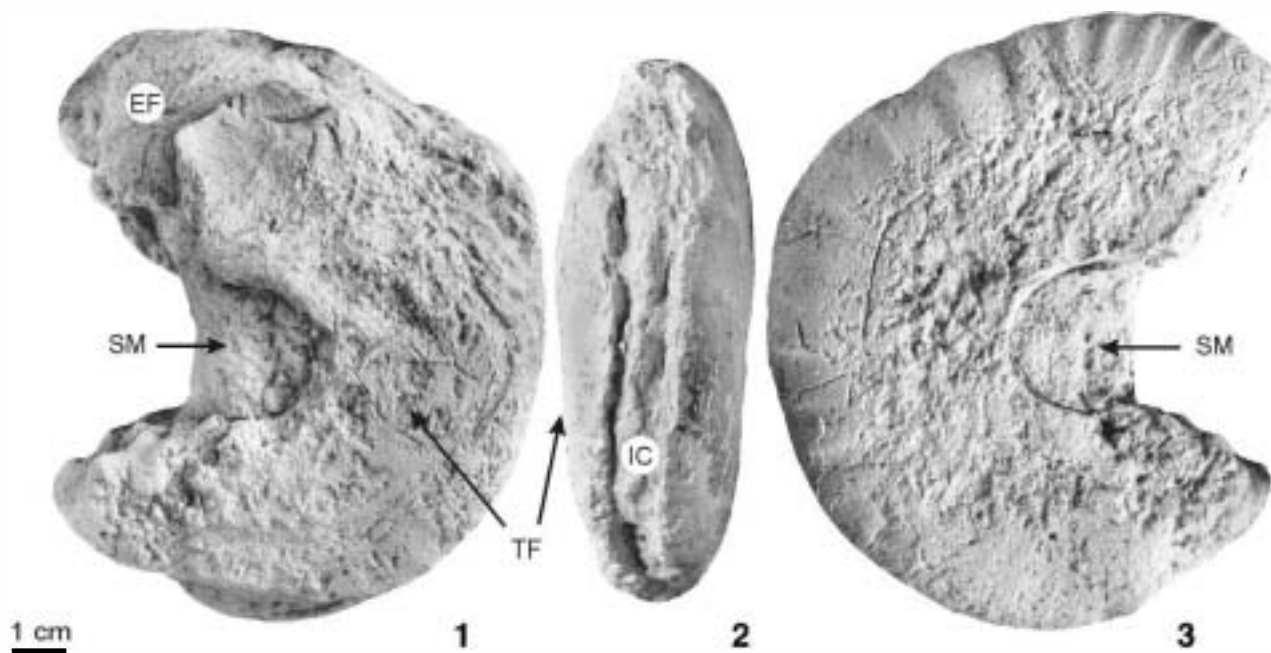


Fig. 1. *Ptychophylloceras* sp. Callovian. Arroyofrio Bed, Domeño Formation (cf. Gómez and Fernández-López, 2004). Moscardón (Teruel). Coll. GM, M166/17. Lateral (1, 3) and ventral (2) views. Internal mould of an incomplete phragmocone showing a sinuous fill channel (IC) in the external region, an ellipsoidal facet of abrasion (EF) in the last third of the preserved outer whorl and a truncation facet (TF) in the right whorl side. The fill channel was formed by draft-current processes during re-sedimentation of the shell on the seafloor, before initial burial. The ellipsoidal facet and the truncation facet were due to abrasion processes during ulterior reelaboration (i.e., exhumation and displacement before final burial) of the concretionary internal mould. The narrow and relatively deep infill channel displays sharp and prominent borders, and has even smaller width in some of the most superficial portions of the internal mould. Inner whorls or nucleus of the phragmocone (diameter less than 50 mm) are not preserved, due to destruction of the hollow camerae during reelaboration. The volume of the nucleus was occupied by sedimentary matrix (SM) during final burial. Specimens figured here and in subsequent figures are whitened with magnesium oxide prior to photography.

Fig. 1. *Ptychophylloceras* sp. Callovien. Couche Arroyofrio, Formation Domeño (cf. Gómez et Fernández-López, 2004). Moscardón (Teruel). Coll. GM, M166/17. Vues latérales (1, 3) et ventrale (2). Moule interne d'un phragmocône incomplet, avec un canal sinueux de remplissage sédimentaire (IC) dans la région ventrale ou externe, une facette ellipsoïdale d'abrasion (EF) dans le dernier tiers de spire conservé et une facette de troncature (TF) dans le flanc droit. Le canal de remplissage a été formé par la circulation de l'eau à travers le phragmocône pendant des processus de résédimentation de la coquille sur le fond marin, avant l'enfouissement initial. La facette ellipsoïdale et la facette de troncature ont été formées à la suite des processus d'abrasion ultérieurs du moule interne, à l'état de concrétion calcaire, pendant la réélaboration (i.e., exhumation et déplacement avant l'enfouissement final). Le canal sinueux de remplissage sédimentaire montre des bords aigus et proéminents ; il est étroit et relativement profond, et il est même plus étroit dans certaines portions plus superficielles du moule interne. Les tours internes ou nucleus du phragmocône (diamètre inférieur à 50 mm) ne sont pas conservés, par destruction des chambres vides et sans remplissage sédimentaires pendant la réélaboration. Le volume du nucleus a été occupé par la matrice sédimentaire (SM) pendant l'enfouissement final. Les spécimens de cette figure et des suivantes ont été blanchis à la fumée de magnésium.

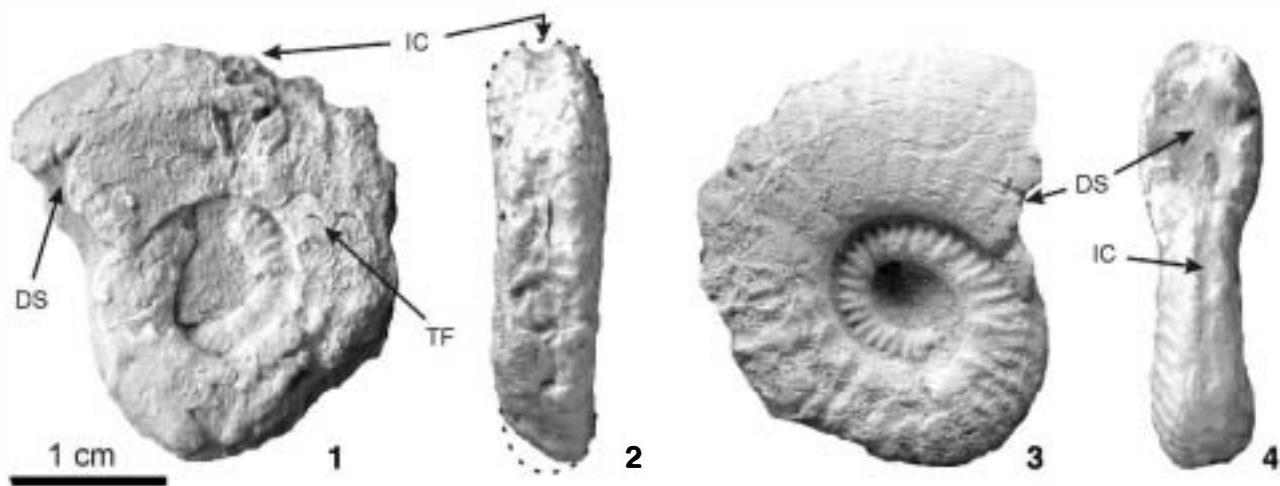


Fig. 2. *Sonninia* sp. Lower Bajocian. El Pedregal Formation (cf. Gómez and Fernández-López, 2004). Moscardón (Teruel). Coll. SRFL, M00/1. Lateral (1, 3), ventral (2) and oral (4) views. Internal mould of an incomplete phragmocone, showing a discontinuous fill channel (IC) in the external region, a truncation facet (TF) in the right flank, and a disarticulation surface (DS) at the end of the preserved outer whorl. Inner whorls of the phragmocone (diameter less than 6 mm) are not preserved, by destruction of the hollow camerae during reelaboration, and their volume was occupied by sedimentary matrix during final burial. The truncation facet is cutting the septa of the phragmocone. The disarticulation surface, developed along the boundary between sedimentary infills of contiguous chambers, represents a structural discontinuity with the sedimentary matrix.

Fig. 2. *Sonninia* sp. Bajocien inférieur. Formation El Pedregal (cf. Gómez et Fernández-López, 2004). Moscardón (Teruel). Coll. SRFL, M00/1. Vues latérales (1, 3) ventrale (2) et orale (4). Moule interne d'un phragmocône incomplet, avec un canal discontinu de remplissage sédimentaire (IC) dans la région externe, une facette de troncation (TF) dans le flanc droit, et une surface de désarticulation (DS) dans la partie terminale de la spire conservée. Les tours internes du phragmocône (diamètre inférieur à 6 mm) ne sont pas conservés, par destruction des chambres vides sans remplissage sédimentaire pendant la réélaboration, et leur volume a été occupé par la matrice sédimentaire pendant l'enfouissement final. La facette de troncation coupe les cloisons du phragmocône. La surface de désarticulation, développée à la limite des remplissages sédimentaires des chambres voisines, représente une discontinuité structurale avec la matrice sédimentaire.

sedimentation and low rate of sediment accumulation, would favour the development and preservation of complete and homogeneous concretionary internal moulds of ammonoids showing draft-filling spiral channel and evidence of early mineralization. Conversely, proximal and shallow palaeoenvironments, in expanded deposits of low rate of sedimentation but

high rate of sediment accumulation, were favourable for development and preservation of partial and heterogeneous concretionary internal moulds of ammonoids showing draft-filling spiral channel and evidence of early mineralization.

Nevertheless, the input of sedimentary particles into the shell cavities by draft-current processes was not the only filling

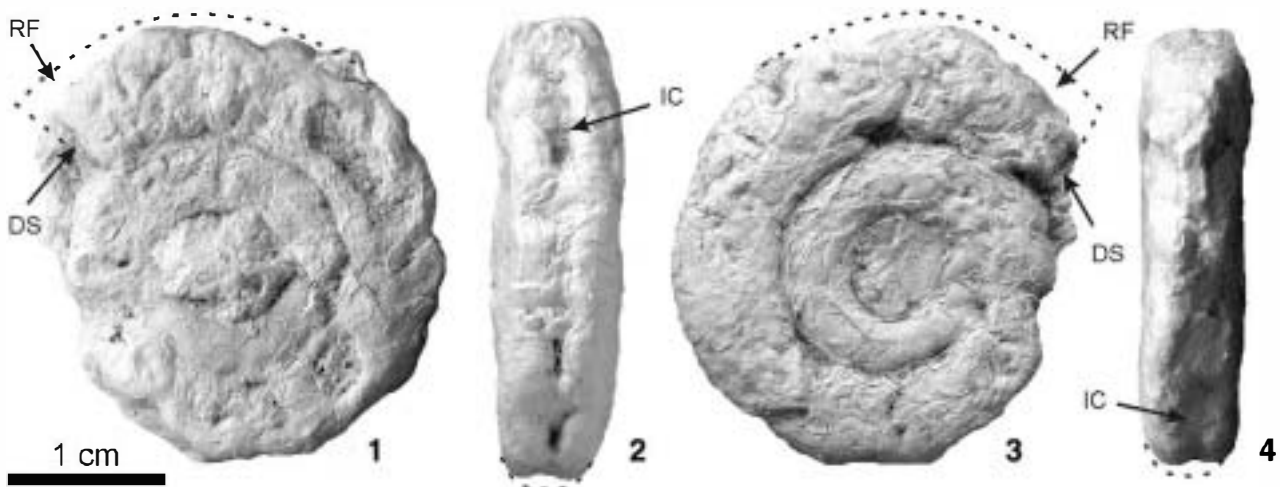


Fig. 3. *Nannolytoceras* sp., Toarcian. Top of the Zegrí Formation (cf. Sandoval and Checa, 2002; Caracuel et al., 2004). Cerro de la Cruz, La Romana (Alicante). Coll. SRFL, CC00/1. Lateral (1, 3), ventral (2) and oral (4) views. Iron-crust coated internal mould of an incomplete phragmocone, showing a discontinuous fill channel (IC) in the external region, as well as a disarticulation surface (DS) in the terminal part of the preserved outer whorl, and a roll facet (RF) preferentially developed on the most prominent portion.

Fig. 3. *Nannolytoceras* sp., Toarcien. Toit de la Formation Zegrí (cf. Sandoval et Checa, 2002; Caracuel et al., 2004). Cerro de la Cruz, La Romana (Alicante). Coll. SRFL, CC00/1. Vues latérales (1, 3) ventrale (2) et orale (4). Moule interne d'un phragmocône incomplet, avec encroûtements ferrugineux, que montre un canal discontinu de remplissage sédimentaire (IC) dans la région externe, ainsi qu'une surface de désarticulation (DS) en position terminale et une facette de roulement (RF) préférentiellement développée dans la partie la plus proéminente et terminale des tours de spire conservés.

mechanism giving rise to the formation of sedimentary internal moulds of ammonoid shells. The input of sedimentary particles inside the ammonoid shells could also happen by gravitational infiltration and bioturbation, as regards the occurrence of lithoclasts of centimetric size, as well as bioturbation textures and structures, in some internal moulds of ammonoids (Fig. 4; Henderson and McNamara, 1985; Fernández-López, 1997a).

3. Abrasion furrows

Abrasion or the mechanical wearing away of taphonomic elements preserved in marine environments is usually due to the impact on them of particles transported by the water or to the friction among the own taphonomic elements that are moved. In both cases, the external surface of taphonomic elements can be polished, and its positive reliefs can be worn away and even obliterated. Nevertheless, taphonomic elements can be abraded only in a portion of their surface and acquire a waste facet (Müller, 1979; Brett and Baird, 1986; Brett, 1990). Truncation facets were formed when the taphonomic elements were fixed or anchored to the substratum and exposed to the action of some abrasive agent. Under such conditions, a unidirectional current will produce a single facet; but several truncation or anchorage facets can be formed in the same taphonomic element, by changes in the direction of the currents or in the position of the abraded element. In contrast, roll or rounding facets tend to be developed on the most prominent superficial reliefs of the taphonomic elements, when they stay loose on the substrate, free of sedimentary matrix, and subjected to the action of abrasive agents. Unlike truncation facets, roll facets tend to increase the degree of roundness and sphericity of the taphonomic elements.

Under the action of bottom currents in subtidal environments, internal moulds of ammonoids would tend to be abraded on one side and develop truncation facets (Figs. 1, 2 and 4)). Under the action of wave (oscillatory) currents in shallow subtidal environments, however, concretionary moulds would tend to overturn and develop roll facets (Fig. 3). Abrasion annular furrows and abrasion ellipsoidal facets (Fig. 5) were developed on free-rotating internal moulds, subjected to directional water currents.

The origin of abrasion annular furrows and ellipsoidal facets carved on the internal moulds of ammonoids is explained by the action of directional, non-oscillatory currents, under extremely shallow bathymetric conditions (Fernández-López and Meléndez, 1994, 1995). Once exhumed and free of sedimentary matrix, and settled on a uniform and consolidated substrate, the reelaborated, concretionary internal moulds should be able to rotate and reorient. Reelaborated moulds having the centre of gravity far apart from the geometric centre and localized in the last third of the last preserved whorl, will tend to reorient the last portion of the outer whorl upstream, this portion hence being differentially abraded. An ellipsoidal facet would be first developed in the last portion of the outer whorl, and then the worn area would progress along the venter to carve a whole annular furrow. The water layer should be similar in thickness to the concretionary mould, so the ornamentation is preserved on the upper side of the mould. Specimens bearing such abrasion structures are platycone and cadycone moulds, and never globular sphaerocones or oxycones. These abrasion structures have only been observed on internal moulds showing a ratio of whorl thickness to diameter between 0.35 and 0.60, and ranging in diameter between 50 and 250 mm.

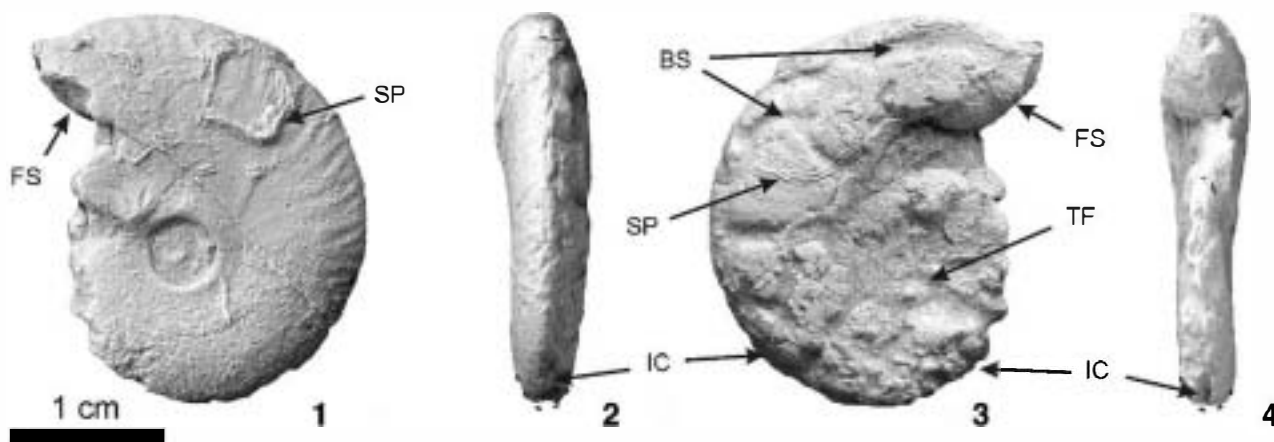


Fig. 4. *Bradfordia* sp. Lower Bajocian. Rebollo de la Torre (Burgos; cf. Pujalte et al., 1988; Robles et al., 1989). Coll. SRFL, 3RE00/1. Lateral (1, 3), ventral (2) and oral (4) views. Internal mould of an incomplete phragmocone showing a discontinuous fill channel (IC) in the external region, a truncation facet (TF) capping bioturbation structures (BS) in the left flank, diverse remains of encrusting organisms (serpules, SP), and a fracture surface (FS) at the end of the preserved outer whorl that represents a structural discontinuity with the sedimentary matrix. The bioturbation structures were formed in a soft sedimentary infill of the shell, before early carbonate cementation and abrasion of the internal mould associated with reelaboration processes.

Fig. 4. *Bradfordia* sp. Bajocien inférieur. Rebollo de la Torre (Burgos; cf. Pujalte et al., 1988; Robles et al., 1989). Coll. SRFL, 3RE00/1. Vues latérales (1, 3) ventrale (2) et orale (4). Moule interne d'un phragmocône incomplet, présentant un canal discontinu de remplissage sédimentaire (IC) dans la région externe, une facette de troncation (TF) que coupe des traces de bioturbation (BS) dans le flanc gauche, divers restes d'organismes encroûtants (serpules, SP) et une surface de fracture (FS) dans la partie terminale de spire conservée qui représente une discontinuité structurale avec la matrice sédimentaire. Les structures de bioturbation ont été formées dans le remplissage sédimentaire de la coquille, quand il était encore en état mou, avant la cimentation carbonatée précoce et l'abrasion du moule interne associé à des processus de réélaboration.

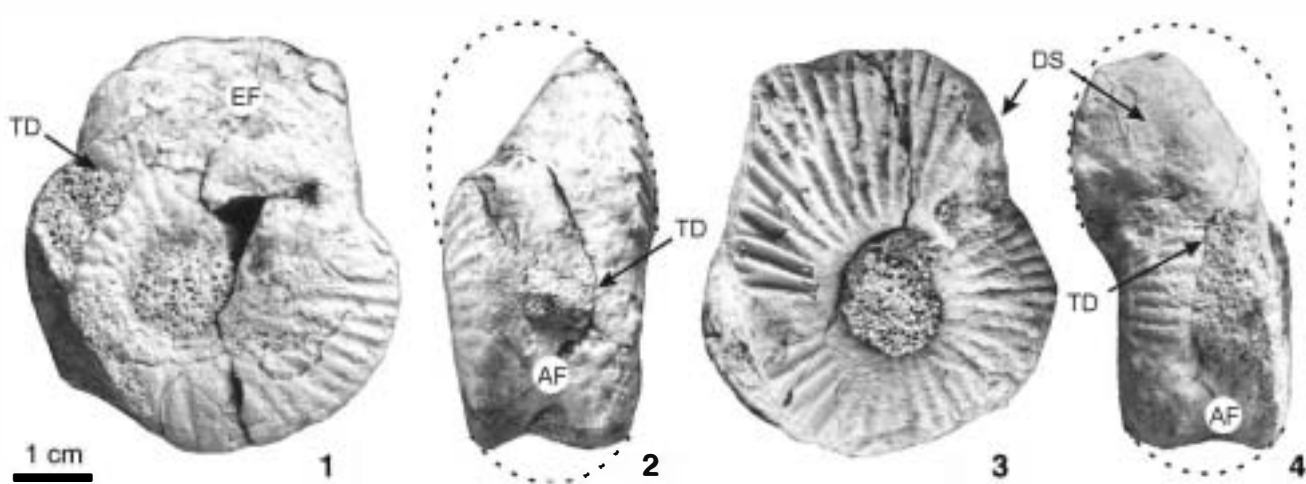


Fig. 5. *Macrocephalites* sp. Lower Callovian. Arroyofrio Bed, Domeño Formation (cf. Gómez and Fernández-López, 2004). Moscardón (Teruel). Coll. SRFL, 3M166/4. Lateral (1, 3) ventral (2) and oral (4) views. Internal mould of an incomplete phragmocone showing an abrasion ellipsoidal facet (EF) on the last third of preserved outer whorl, an abrasion annular furrow (AF) on the whole venter and a disarticulation surface (DS) at the end of the preserved outer whorl. The abrasion annular furrow is wide and shallow and shows rounded edges. Note the structural discontinuity (TD) between the micritic sedimentary infill and the oolitic sedimentary matrix, associated with abrasion surfaces and iron-crusts coating on the internal mould.

Fig. 5. *Macrocephalites* sp. Callovien inférieur. Couche Arroyofrio, Formation Domeño (cf. Gómez et Fernández-López, 2004). Moscardón (Teruel). Coll. SRFL, 3M166/4. Vues latérales (1, 3) ventrale (2) et orale (4). Moule interne d'un phragmocone incomplet, avec une facette ellipsoïdale d'abrasion (EF) dans le dernier tiers de spire conservée, un sillon annulaire d'abrasion (AF) dans la région ventrale et une surface de désarticulation (DS) dans la partie terminale de la spire conservée. Le sillon annulaire d'abrasion montre des bords arrondis ; il est large et peu profond. Notez la discontinuité structurale (SD) entre le remplissage sédimentaire micritique et la matrice oolitique, associée à la présence des surfaces d'abrasion et des encroûtements ferrugineux dans le moule interne.

Early cemented or concretionary internal moulds of ammonoids bearing abrasion annular furrows are common in Jurassic carbonate rocks, within shallow epicontinental platforms deposits. They are usually found in condensed sections, formed by expanded sediments, and associated with sedimentary discontinuities and indurate surfaces, ranging from firmgrounds to hardgrounds (Fernández-López, 1985, 1995, 1997a, 1997b, 2000a, 2000b; Aurell et al., 1994, 2004; Fernández-López et al., 1996; Ramajo and Meléndez, 1996; Meléndez et al., 2002). From a palaeoenvironmental point of view, abrasion annular furrows are useful as indicators of turbulent waters, high energy environments, and low rate of sedimentation. From a palaeogeographic point of view, these abrasion structures are indicative of extremely shallow bathymetric conditions, intertidal and peritidal environments being the most favourable.

4. Distinction between draft-filling channels and abrasion furrows

Draft-filling channels of the shells and abrasion furrows of the sedimentary internal moulds may display similar properties, such as preferential development on the external region of sedimentary internal moulds. However, they differ in morphological characters, mechanisms, palaeoenvironments and palaeogeographic conditions of formation.

Draft-filling channels of the shells display the following characteristic features:

- They can be either superficial grooves and subsurface conducts and are preserved on sedimentary internal moulds, passing through the septal orifices of the phragmocone or

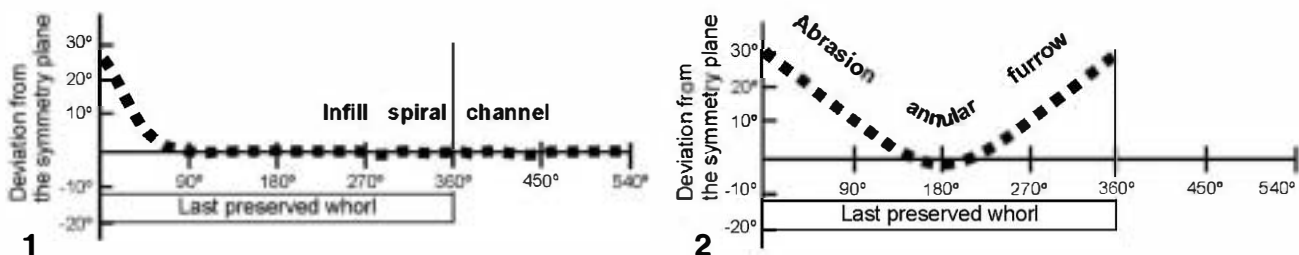


Fig. 6. Diagram showing the deviation from the symmetry plane of the draft-filling spiral channels (1) and the abrasion annular furrows (2) developed on ammonoid internal moulds.

Fig. 6. Schéma de déviation par rapport au plan de symétrie des canaux spiraux de remplissage (1) et des sillons annulaires d'abrasion (2) développés dans les moules internes d'ammonoïdes.

- connecting the last septal foramen with the opening of the body chamber;
- they tend to display a spiral shape (Fig. 6(1));
- they can reach the inner whorls, surpassing 360° in length, being conditioned by the spiral geometric form of the shell wall;
- they are located near the sagittal plane of the shell in the phragmocone, conditioned by the sagittal position of consecutive septal foramens; however, they can become asymmetric (deviation greater than 30° from the symmetry plane) attaining a lateral position from the last septal foramen to the aperture;
- they show sharp and prominent borders, developed by accretion of fill sediments inside the chambers of the phragmocones, although they can display gentle edges in the body chambers;
- they are usually narrow and deep, showing their maximum depth in any point of the last preserved whorl;
- they tend to disappear irregularly, sometimes diminishing in depth towards the apical chambers.

In contrast, abrasion furrows are developed on concretionary internal moulds and display the following characteristic features:

- they are superficial grooves carved on the sedimentary internal moulds, cutting the septa of the phragmocone along the ventral region;
- they tend to display a ring shape (Fig. 6(2));
- they are restricted to the last preserved outer whorl, not surpassing 360° in length;
- they are only developed on the ventral region, not on the flanks. However, they move away from the sagittal line in the last and the first quarter of the preserved outer whorl (between 0-90° and 270-360° respectively); nevertheless, deviation with respect to the sagittal plane of the shell is less than 30°, maintaining a ventral position in the last third part of the last preserved whorl (where the shell reaches higher width values, be it the body chamber or the phragmocone);
- they show rounded borders, developed by abrasion of external surfaces of the sedimentary infill of the chambers;
- they are usually wide and shallow, showing their maximum depth in the last third of the preserved outer whorl;
- they tend to disappear gradually, diminishing in depth and becoming progressively shallower towards the diametrically opposed point to that of the end of the last preserved whorl.

In addition to the morphological differences, these taphonomic structures were formed by separate and independent processes. Draft-filling spiral channels were developed during resedimentation processes (i.e., displacement of the shells on the seafloor before initial burial), whereas abrasion annular furrows were developed during taphonomic reworking or reelaboration processes (i.e., exhumation and displacement on the seafloor of early cemented or concretionary internal moulds, before final burial in younger or contemporaneous deposits).

The sedimentary infill of ammonoid internal moulds bearing abrasion annular furrows is petrographically discontinuous

with the fabric of the enclosing sedimentary rock. Abrasion ellipsoidal facets and abrasion annular furrows cut the fabric of the internal moulds and have a counterpart impression in the sedimentary matrix around the fossil. In contrast, the sedimentary infill of ammonoid internal moulds bearing draft-filling spiral channels can be petrographically continuous or discontinuous with the fabric of the sedimentary matrix. Similarly, they can display or not a counterpart impression in the enclosing rock. On the one hand, reelaborated internal moulds bearing a draft-filling channel display a counterpart impression in the enclosing rock and are petrographically discontinuous with the fabric of the sedimentary matrix. On the other hand, internal moulds of resedimented shells bearing a draft-filling channel do not display a counterpart impression in the enclosing rock and are petrographically continuous with the fabric of the sedimentary matrix.

From a palaeoenvironmental point of view, draft-filling spiral channels and abrasion annular furrows are taphonomic structures useful as indicators of turbulent regimes and conditions of low rate of sedimentation in marine subtidal environments, associated with condensed sections. From a palaeogeographic point of view, draft-filling spiral channels on complete and homogeneous sedimentary internal moulds were formed in conditions of low rate of sediment accumulation, under distal and deep bathymetric conditions. Conversely, draft-filling spiral channels on partial or heterogeneous sedimentary internal moulds were formed in conditions of low rate of sedimentation but high rate of sediment accumulation, under proximal and shallow bathymetric conditions. In contrast, abrasion annular furrows were produced under extremely shallow bathymetric conditions, intertidal and peritidal environments being the most favourable.

5. Conclusions

Draft-filling spiral channels and abrasion annular furrows, preferentially developed on the external region of ammonoid sedimentary internal moulds, can be distinguished by morphological and genetic criteria.

Draft-filling spiral channels are (sub-)superficially developed, passing through the septal foramens of the phragmocone or connecting the last septal foramen with the opening of the body chamber; they are relatively narrow and deep, showing sharp edges; they can occur either on reelaborated internal moulds petrographically discontinuous with the fabric of the sedimentary matrix, and displaying a counterpart impression in the enclosing rock, or on resedimented elements petrographically continuous with the fabric of the sedimentary matrix, without a counterpart impression in the enclosing rock. In contrast, abrasion annular furrows are superficially developed, cutting the septa of the phragmocone; they are relatively wide and shallow, showing rounded edges; they occur on internal moulds petrographically discontinuous with the fabric of the sedimentary matrix; and they display a counterpart impression in the enclosing rock.

Both types of taphonomic structures were formed in marine environments, under turbulent regimes and low rate of

sedimentation conditions, before final burial. Draft-filling spiral channels were formed during re-sedimentation processes, associated with complete and homogeneous sedimentary internal moulds in distal and deep environments, and partial or heterogeneous sedimentary internal moulds in proximal and shallow environments. Abrasion annular furrows were formed during taphonomic reworking or reelaboration processes under extremely shallow bathymetric conditions, in intertidal and peritidal environments.

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